Batteries and the Circular Economy

RSR Technologies, Inc.

2017

Five major technological innovations are serving the growing worldwide population and rising middle class.

Internet

Internet of things

Renewables

Advanced Materials

Rechargeable Batteries

Let’s focus on advanced materials and rechargeable batteries as *enablers.*

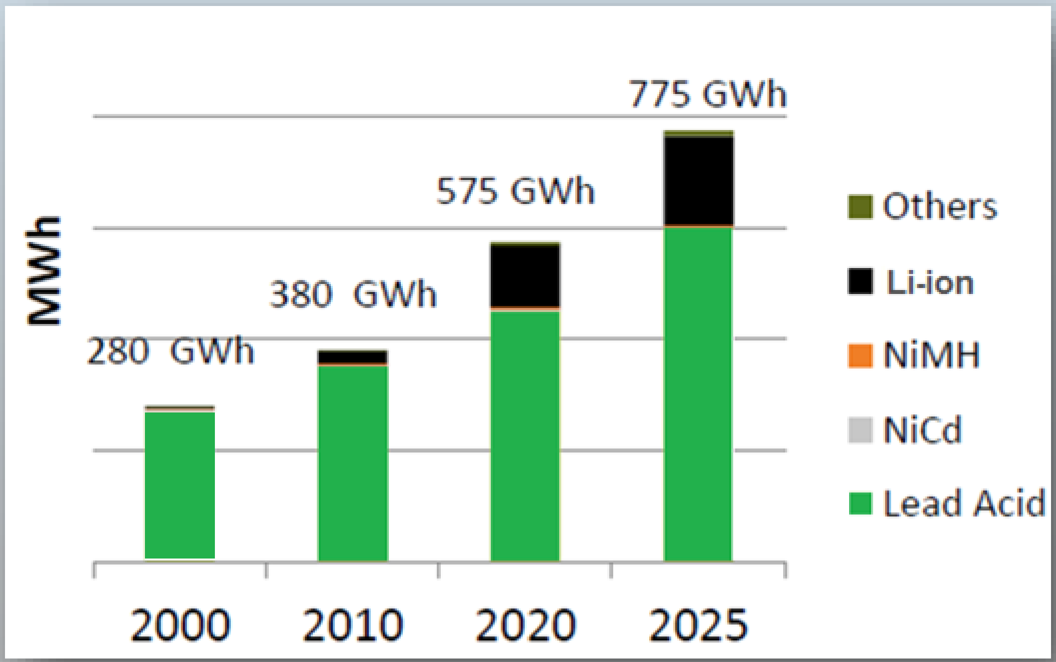





Rechargeable batteries are needed more than ever for the growing worldwide population.

Worldwide Rechargeable Battery Sales

Estimated Projection



Source: Avicenne

Batteries face several challenges

Longer life

More power

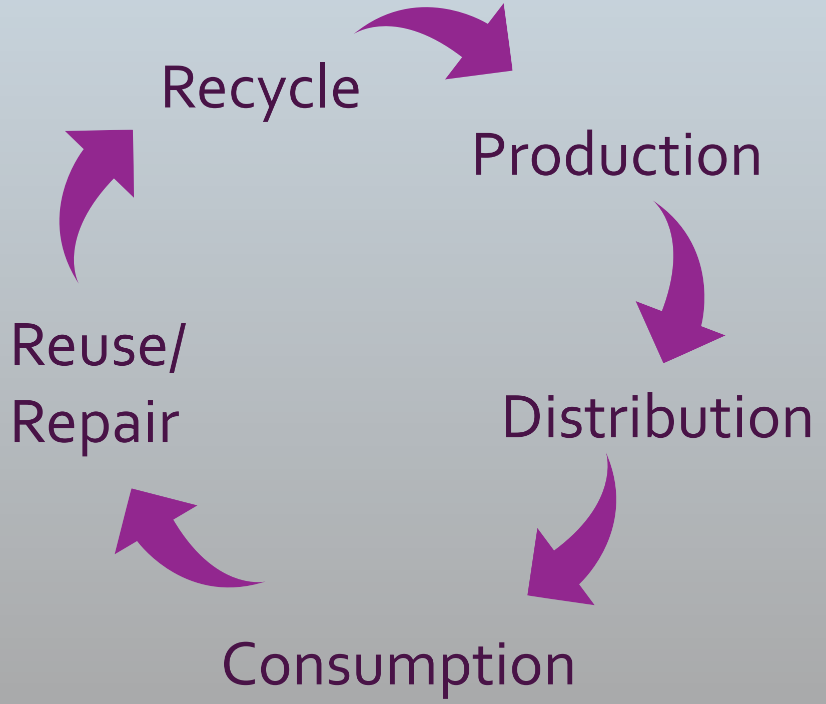
More safe

Lower life-cycle cost

Each challenge is important, but life-cycle cost has been receiving inconsistent attention by government and industry.

As batteries become more important, their life-cycle needs to move from *linear*…

…to *circular* materials management.



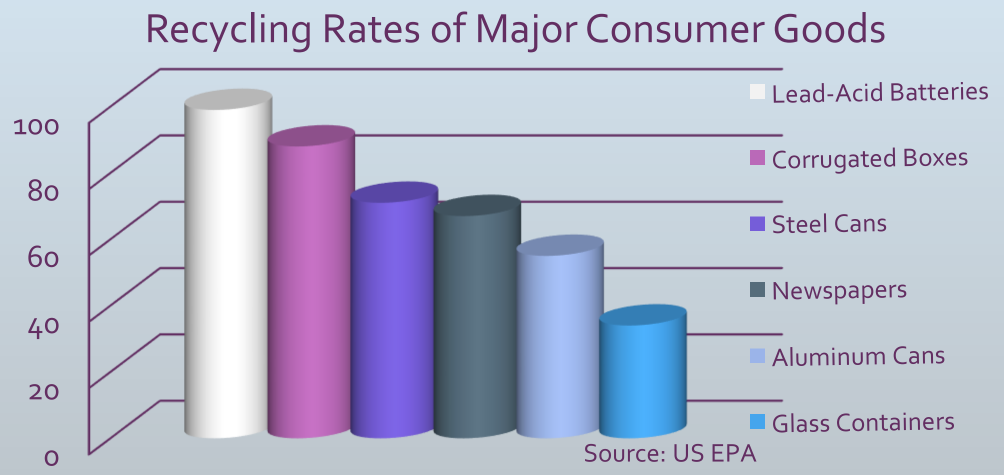
Can batteries meet the life-cycle recycling challenge? Does a model already exist?

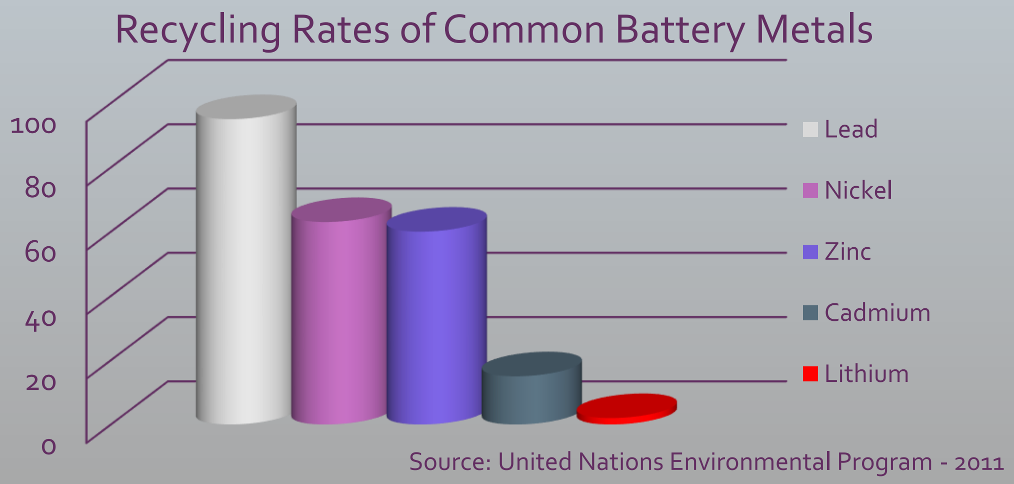
With one important exception, many rechargeable batteries are not recycled profitably because the price of recycled materials is higher than the price of virgin materials.

The exception is lead-acid batteries, which are 99% recycled because the price of recycled materials is competitive with virgin materials.

No other battery chemistry is yet able to equal lead-acid's closed loop recycling process and profitability.

Lead-acid's circular business structure is a model for other battery chemistries.





Dealing with the remaining one per cent is a priority issue for the lead industry.

One perspective

- The secondary lead industry has done a remarkable job during the past 50 years to achieve a 99% recycling rate.
- The remaining one per cent is mostly “slag” that contains iron, lead, aluminum and other materials.
- Recovering this remaining one per cent is technically and economically challenging, but remains an important priority for the lead industry.

Another perspective

- Strict regulatory standards in the U.S. are not reflected in many other parts of the world.
- These standards are expensive and compliance has helped make the U.S. lead-acid battery recycling industry the world’s best.
- But, when other countries do not have such standards, recyclers have lower overhead and become “pollution havens” for scrap dealers who make more money selling used batteries to poorly-run processors outside the U.S.

Why should we care about recycling? One reason is safety.

Safe operation is one part of the story.

Safe end-of-life management is another part.

Explosions of discarded lithium-ion batteries are occurring in garbage trucks, landfills, warehouses and recycling plants.

Why is the lithium-ion recycling rate so low?

- Lack of design for recycling.
- Inadequate collection and delivery infrastructure.
- Insufficient incentives for consumers to place discarded batteries into recycling stream.
- Residual value ends up in landfills rather than recycled.

Why else should we care about recycling? Another reason is economics.

Re

Recycling…

- ✓ Reduces life-cycle costs by saving energy and cutting pollution
- ✓ Reduces the need for mining
- ✓ Reduces the need for landfills
- ✓ Reduces material imports
- ✓ Facilitates efficient use of critical materials
- ✓ Reduces legal risk for producers/customers
- ✓ Generates income

Recyclers take feedstock from "mines" like this…

…and produce materials for new batteries.

How major battery chemistries compare on the circular end-of-life paradigm.

	Lead-acid	Lithium-ion	Nickel Metal Hydride	Supercapacitors
Standard chemistry design	Yes	No	Yes	Yes
Design compatible with recycling	Yes	No	No	No
Recycled materials used in new batteries	Yes	No	No	No
Recycling cost embedded in retail price	Yes	No	No	No
Battery end-of-life management rate*	99%	<5%	<60%	<10%
Notes:	Most recycled lead is used in new lead-acid batteries.	Some cobalt recycled. Other materials "downcycled," i.e, road slag.	Nickel Metal Hydride batteries are not recycled. Rather, most nickel is "downcycled" for use in stainless steel production.	Not currently subject to material recovery operation.

*Source: US EPA, USGS

Major rechargeable battery chemistries and their environmental issues.

Battery Chemistry | **Environmental/Safety Considerations**

Lead-acid

Lead-acid batteries are based on a design (lead plates and sulfuric acid) that has stood the test of time for more than 150 years. Lead enables stable and reliable current flow through the battery.

Lead is regulated in the U.S. under universal hazardous waste laws. Exposure can lead to hypertension, high blood pressure, reproductive abnormalities and other adverse conditions.

Lithium-ion

Li-ion batteries, which feature attractive energy density, are made from metal oxides and/or phosphates with combinations of manganese, cobalt, nickel, iron, titanium, etc.

Reaction with water is particularly dangerous because of simultaneous heat development and formation of hydrogen gas, which can result in explosion or fire.

Nickel Metal Hydride

Nickel Metal Hydride (NiMH) batteries are comprised mostly of nickel. However, the use of lanthanides (rare earths) and other "specialty" elements adds complexity to the design.

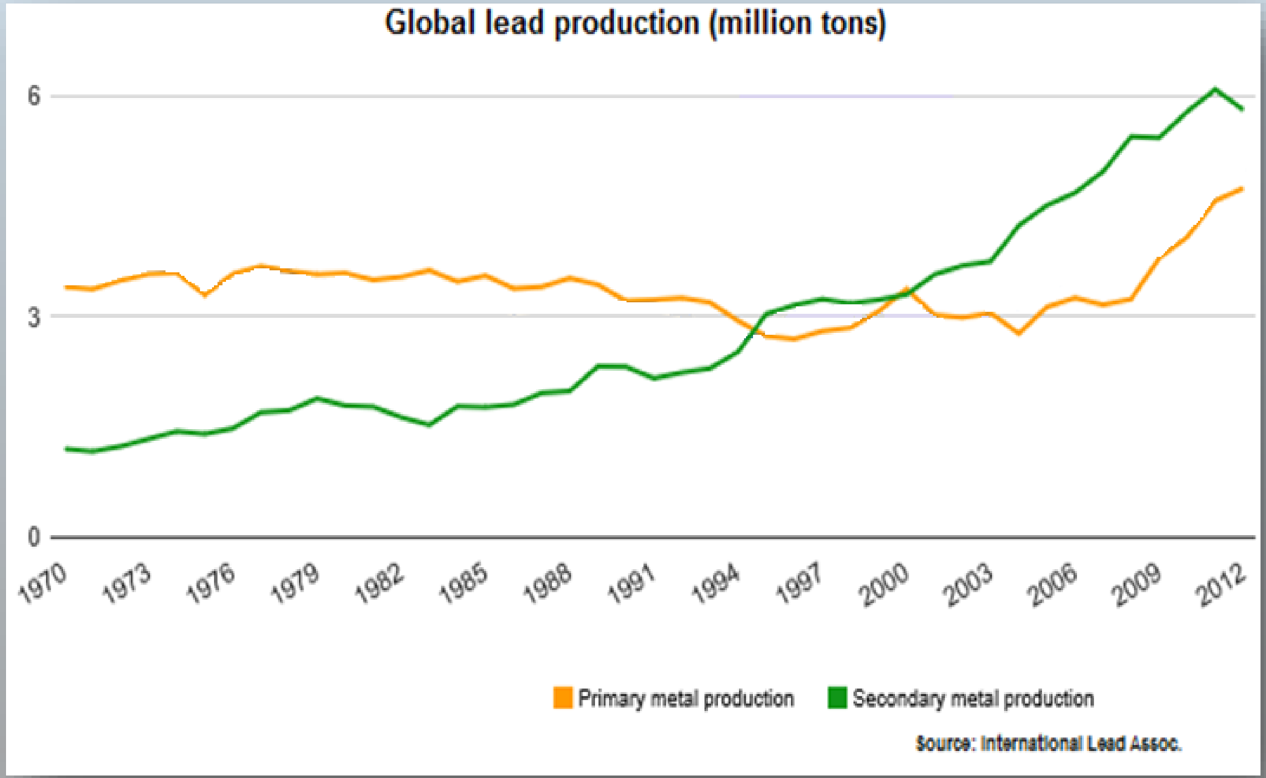
Under-regulated rare earth elements can produce wastewater and tailings ponds that leak acids, heavy metals and radioactive elements into groundwater.

Supercapacitors

Where batteries produce, store and discharge energy from an electrochemical reaction, supercapacitors store energy from a static charge. They are useful for high discharge applications.

Materials used can present environmental issues of fine particulate carbon and cyanogen containing flammable organics.

What recycling has meant in the lead industry.



For nearly 50 years, technological improvements have allowed dramatic growth in the lead secondary (recycling) industry's production to keep pace with the production of lead from primary (virgin) resources.

Some lead production from primary resources remains necessary to meet rising overall demand.

Recycling creates a second source of supply that helps stabilize the commodity price of lead.

Is it possible to recycle lithium-ion and other advanced batteries? Yes, but…

Various end-of-life technologies exist:

- Pyrometallurgical recycling
- Hydrometallurgical recycling

Mostly for "downcycling" materials for lower grade uses such as road slag.

- Direct recycling – a promising new approach:
  - Recover the entire active cathode material instead of individual elements.
  - Physically crush battery electrodes, separating materials using sieves or magnets, and then purifying them.
  - However, direct recycling is in its infancy and matching marketable battery designs with recycled materials is difficult.

Bottom Line: Recycling advanced batteries like lithium, nickel and other chemistries, is technically feasible, but difficult. (Pyrometallurgy works economically for lead, but not for lithium.) Plus, there is little incentive for battery manufacturers to integrate recyclability into product design.

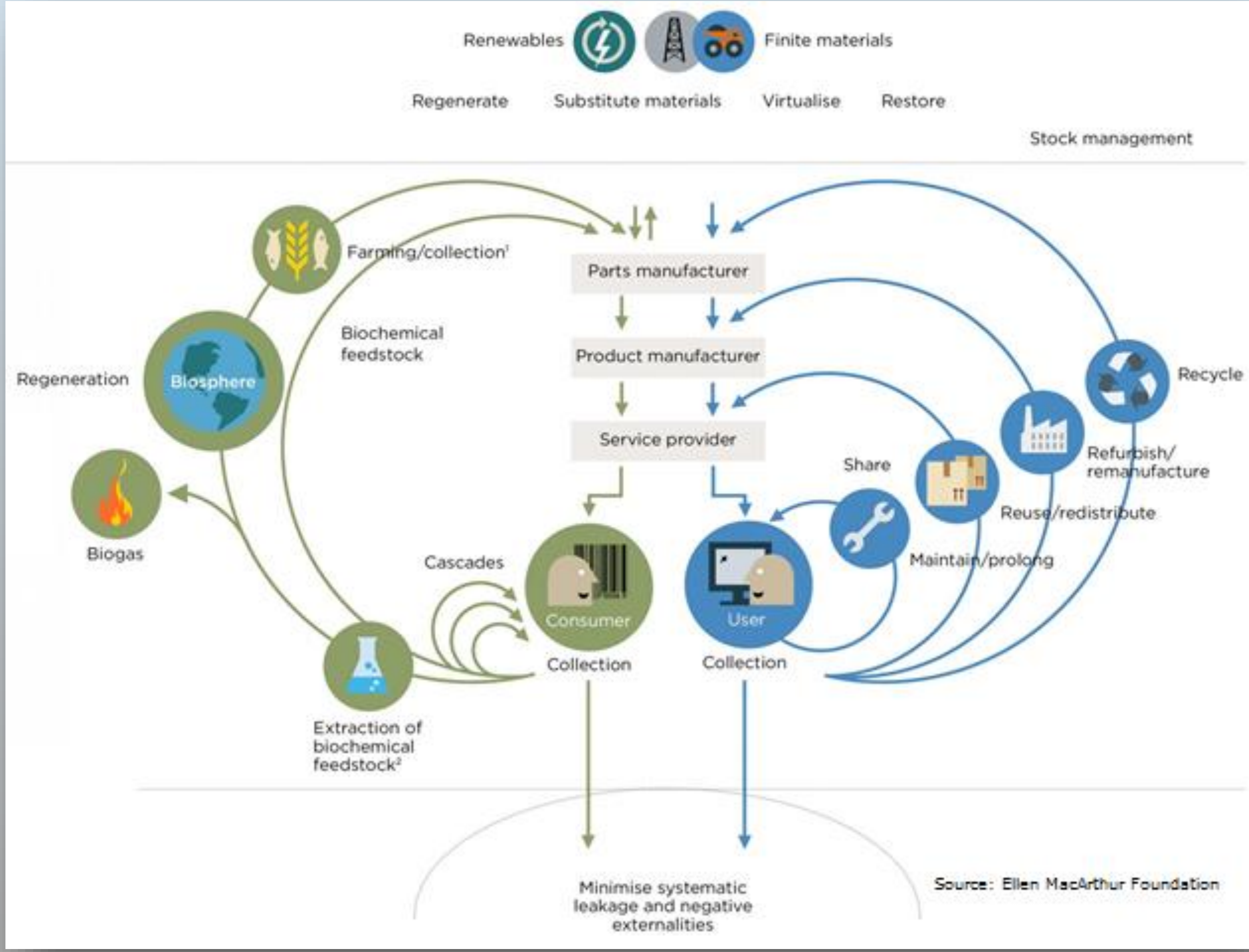
To be traded as commodities, recycled materials must meet high standards.

Primary and secondary lead contracts are traded on the London Metal Exchange (LME).

> Other non-ferrous metals traded on LME include aluminum, copper, zinc, nickel, tin. (Cobalt recently added.)

To be traded on the LME, contracts meet high standards of market transparency, financial performance, and regulatory compliance.

We need to understand what recycling is and what recycling is not.



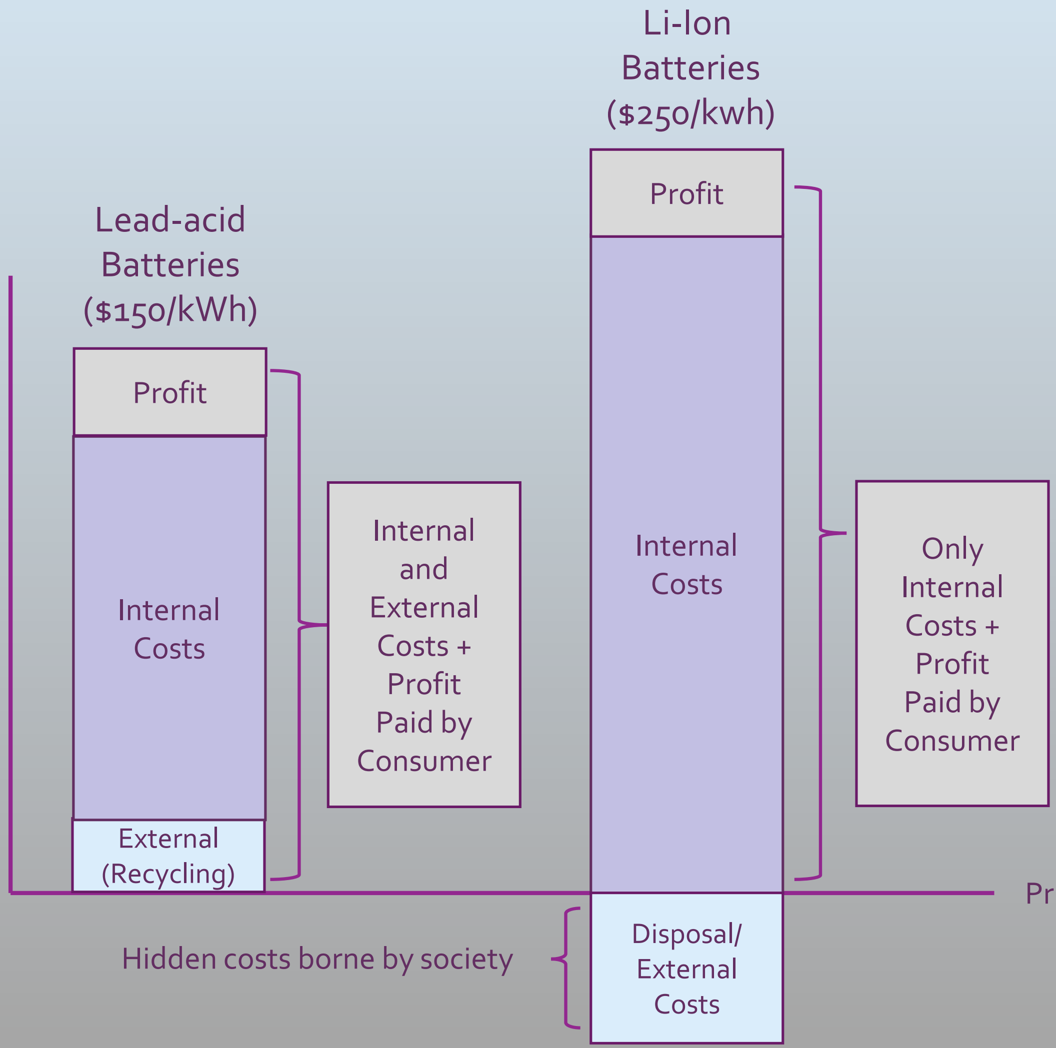
Recycling is the processing of used materials into reusable materials to reduce consumption of "virgin" materials.

To be considered recycled, materials must be competitive (price and function) with primary "virgin" materials.

Recycling is not downcycling, refurbishment or remanufacturing.

While downcycling, refurbishment and remanufacturing serve legitimate functions in a circular economy, they are not a substitute for recycling.

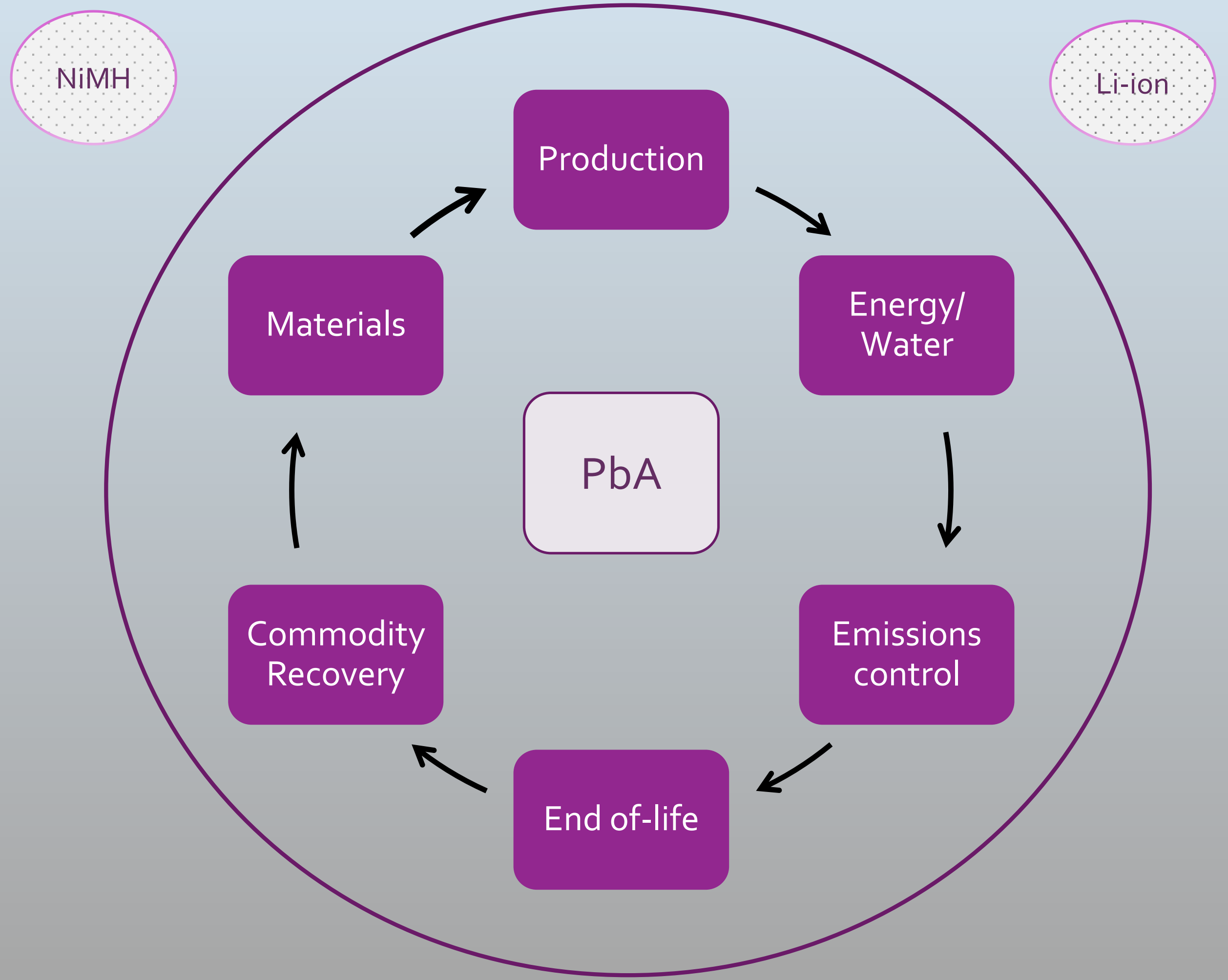
Internal and external costs: What happens when a product is not in the closed loop.



Internal Costs:
- Fixed:
  - General overhead
  - Administration
  - Sales
  - Depreciation
- Variable:
  - Materials
  - Labor
  - Production equipment
  - Energy
  - Recycling

External Costs:
- Disposal
- Environmental mitigation

What's needed? All battery chemistries, not just lead-acid, need to be in the closed loop.



Are these life-cycle components embedded in the retail price of a rechargeable battery?

For of lead-acid (PbA) batteries, the answer is yes. Lead-acid batteries are in the closed loop.

Other battery chemistries, such as lithium-ion & nickel metal hydride, are on the outside looking in.

For these other battery chemistries, considerable work is required to bring them into the closed loop.

A levelized cost of storage calculation is needed.

Making sense of the battery life-cycle management alphabet soup…

US EPA – USDOE – US DOT

USCAR – NARUC

World Economic Forum

Business Roundtable

BCI
NAATBatt
SAE
RBC
ABR
ILA
EUROBAT
BAJ
PRBA
iFixit
BAN
ESA
Call2Recycle
EPEAT
iNEMI
EPBA
IBMA
CIAPS
UPSci

Each can benefit from an understanding of the various perspectives of the other organizations.

Does a collaborative opportunity exist to accomplish that?

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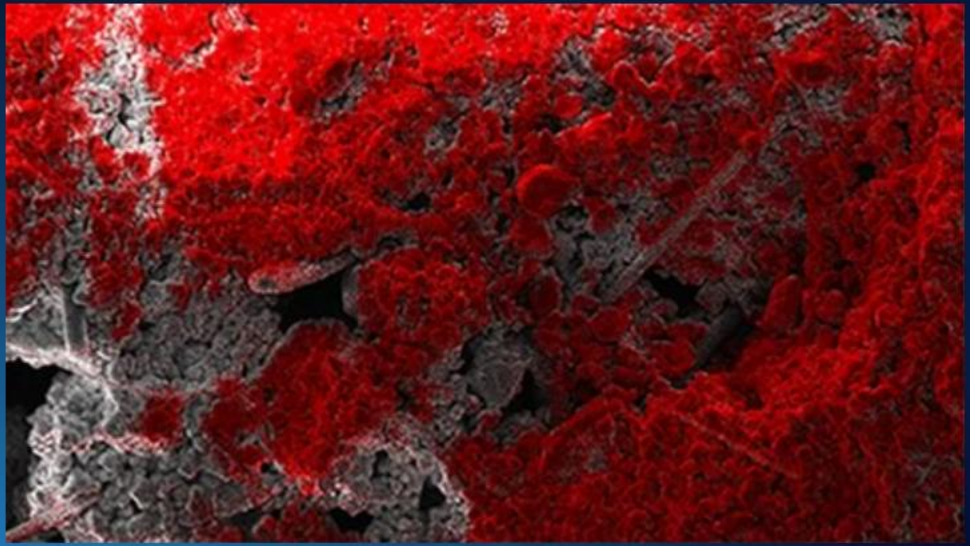

ABOUT RSR TECHNOLOGIES

RSR Technologies is a research and development company engaged in the non-ferrous smelting and refining industries.

The company provides services to battery, mining, and smelting companies. RSR Technologies is focused on achieving the highest standards for health, safety and the environment.

The company provides services worldwide and is headquartered in Dallas, Texas.

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